REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
17-05-2004

REPRINT

4. TITLE AND SUBTITLE
Solar Fast Wind Regions as Sources of Gradual 20 MeV Solar Energetic Particle Events

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
S.W. Kahler

5d. PROJECT NUMBER
2311

5e. TASK NUMBER
RD

5f. WORK UNIT NUMBER
A1

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/VSBXS
29 Randolph Road
Hanscom AFB MA 01731-3010

8. PERFORMING ORGANIZATION REPORT

20040526 039

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/VSBXS

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-VS-HA-TR-2004-1085

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited.

13. SUPPLEMENTARY NOTES
REPRINTED FROM: PROCEEDINGS OF THE 28TH INTERNATIONAL COSMIC RAY CONFERENCE, TSUKUBA, JAPAN, pp 3301-3304, 2003.

14. ABSTRACT

If production of solar energetic particles (SEPs) near the Sun is due to shocks driven by coronal mass ejections (CMEs), then SEP acceleration in slow rather than fast solar wind streams should be favored because both the Alfven and solar wind flow speeds are higher in the fast wind streams. We identify SOHO LASCO fast west-limb or halo CMEs that occurred when the Earth was in fast wind streams indicated by low values of the solar wind O^7/O^6 ratios from the ACE satellite. Those CMEs would be expected to be associated with fewer or weaker SEP events than comparable CMEs in slow wind regions. However, we find no differences between the fast CMEs in fast wind and the fast CMEs in slow wind in terms of their associated SEP intensities or SEP-associated CME speeds.

15. SUBJECT TERMS
Coronal mass ejections
Solar energetic particles
Solar wind plasmas
Solar magnetic fields

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			S. Kahler
UNCLAS	UNCLAS	UNCLAS	SAR	4	**19b. TELEPHONE NUMBER** *(include area code)* 781-377-9665

AFRL-VS-HA-TR-2004-1085

Solar Fast Wind Regions as Sources of Gradual 20 MeV Solar Energetic Particle Events

Stephen Kahler,[1]
(1) Space Vehicles Directorate , AFRL, Hanscom AFB, MA 01731-3010, USA

Abstract

If production of solar energetic particles (SEPs) near the Sun is due to shocks driven by coronal mass ejections (CMEs), then SEP acceleration in slow rather than fast solar wind streams should be favored because both the Alfven and solar wind flow speeds are higher in the fast wind streams. We identify SOHO LASCO fast west-limb or halo CMEs that occurred when the Earth was in fast wind streams indicated by low values of the solar wind O^7/O^6 ratios from the ACE satellite. Those CMEs would be expected to be associated with fewer or weaker SEP events than comparable CMEs in slow wind regions. However, we find no differences between the fast CMEs in fast wind and the fast CMEs in slow wind in terms of their associated SEP intensities or SEP-associated CME speeds.

1. Introduction

A correlation between the peak intensities I_p of $E > 10$ MeV gradual SEP events observed at 1 AU and the speeds V_{cme} of associated fast coronal mass ejections (CMEs) has long been known. This is understood to be a result of SEP acceleration in the corona and interplanetary medium by shocks driven by the fast CMEs [3]. The correlation, however, shows significant scatter of up to 3 to 4 in the logs of I_p, indicating that V_{cme} alone is only one factor in SEP production by driven shocks and that other factors must also be important [6]. Kahler [4] identified enhanced ambient SEP intensities and spectral variations among SEP events as two factors contributing to the scatter of the correlation between log I_p and V_{cme}. Here we consider the required coronal and interplanetary shock wave speeds as another possible factor.

Since V_{cme} must exceed the ambient combined Alfven and solar wind flow speeds, $V_A + V_{flow}$, to drive an MHD shock, it is of interest to see how $V_A + V_{flow}$ varies through the different regions of the corona and inner heliosphere. Kahler and Reames [5, hereafter KR] reviewed work which established that the characteristic speeds of the fast solar wind streams considerably exceed those of slow wind streams, although the differences are difficult to quantify, especially at solar maximum. Since SEPs follow the magnetic field lines convected antisunward by the solar wind, the SEPs observed in fast solar wind streams at 1 AU must be

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produced in the same streams near the Sun. KR [5] used wide (> 60°) and fast ($V_{cme} > 900$ km/s) halo or west limb CMEs as candidates for producing gradual 20 MeV proton SEP events at 1 AU. They found that the solar wind O^7/O^6 ratios measured on the SWICS detector [1] on ACE did not order the peak 20 MeV SEP intensities, even when variations in V_{cme} and solar source longitudes were taken into account. With the criterion that the solar wind $O^7/O^6 < 0.15$ to confirm the identifications of fast wind regions [8], KR [5] found that 5 of the 11 fast CMEs observed in fast solar wind were associated with SEP events. That fraction of CMEs in fast wind was smaller than that for the remaining CMEs, 56/73, for which the solar wind signature was $O^7/O^6 \geq 0.15$. In addition, the median speed of the 5 fast wind CMEs with SEP events was 1336 km/s, while that of the other 56 SEP-associated CMEs was only 1103 km/s. Those two results suggested a possible bias against SEP production in the fast wind regions, but the statistics of the KR [5] study were obviously too small for a definitive determination.

2. Data Analysis

KR [5] selected for analysis fast CMEs appearing as halos or on the west limb and with known solar source locations during the period 1998 to 2000. They also added all CMEs associated with gradual SEP events during the same period. Here we extend that study to the period 2001 to October 2002, for which the SWICS O^7/O^6 values were available on the SWICS web site. We again selected the time intervals when $O^7/O^6 < 0.15$ and then the fast ($V_{cme} > 900$ km/s) west-limb or halo CMEs occurring during those intervals. The CME speeds were taken from the SOHO LASCO CME catalog for 2001, as in the KR [5] study. However, catalog CME data were not available for the 2002 intervals, so additional fast CMEs were selected from movies of Lasco coronagraph subtracted images. In addition, all CMEs associated with SEP events in fast wind intervals during 2001-2002 were included in the study. The enlarged study now includes a first group of fast or SEP-associated CMEs from all fast wind regions of 1998 to 2002 and a second group of CMEs from all other solar wind regions of 1998 to 2000.

The approximate solar source region identification of each CME was required for inclusion in the study. To determine whether a given CME was associated with a SEP event, we required that the ambient 20 MeV proton intensity be less than 10^{-2} p/cm^2 s sr MeV, as in KR [5]. The total number of fast and/or SEP-associated CMEs in the fast wind regions for the period 1998-2002 is now 22, of which 15 are SEP-associated. This establishes that SEP events do occur in fast wind regions. Figure 1 shows solar wind data during the onset of one of the 15 SEP events.

In Figure 2 we show log I_p versus V_{cme} for all CMEs of the study. When no associated SEP event was found, log I_p (20 MeV) was set equal to -3.52 for the CME. The large spread of points is due partially to the fact that CMEs from all

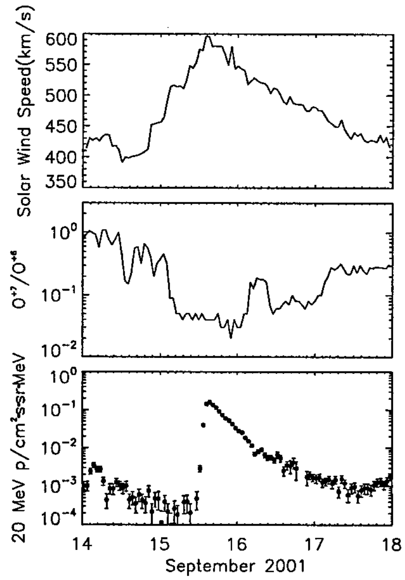

Fig. 1. Plots of solar wind speed (top); O^7/O^6 ratios (middle); and 20 MeV proton intensities (bottom) during the SEP event of 15 September 2001. The SEP event occurred in a high-speed stream as indicated by both a high solar wind speed and low O^7/O^6 ratio. The speed of the associated CME was only 478 km/s, well below the expected required speed to drive a shock in a fast wind region. Since the associated flare occurred in AR 9608 at S21W49, the projected sky speed should not be substantially lower than the intrinsic speed.

solar longitude ranges were included in the graph. The two populations of Figure 2 appear to overlap with no obvious differences. We find that 15 of the 22 (68%) fast CMEs with $O^7/O^6 < 0.15$ are associated with SEP events, comparable to the 76% figure for fast CMEs with $O^7/O^6 \geq 0.15$. Median speeds of SEP-associated CMEs with $O^7/O^6 < 0.15$ are somewhat faster (1245 km/s versus 1103 km/s) than those with $O^7/O^6 \geq 0.15$.

3. Discussion

KR [5] found that 5 of the 11 fast CMEs in fast wind regions of their survey were associated with SEP events, and the speeds of the SEP-associated CMEs were faster than those of the SEP-associated CMEs outside the fast wind regions. They suggested that SEP production by shocks in fast wind regions must occur in polar plumes, where the Alfven speeds are substantially lower than in the interplume regions. Our expanded survey of 22 fast CMEs in fast wind regions now clearly establishes SEP production in fast wind regions as a common phenomenon. Of those 15 SEP-associated CMEs, $V_{cme} < 750$ km/s for three CMEs, showing further that enhanced speeds are not a requirement for SEP

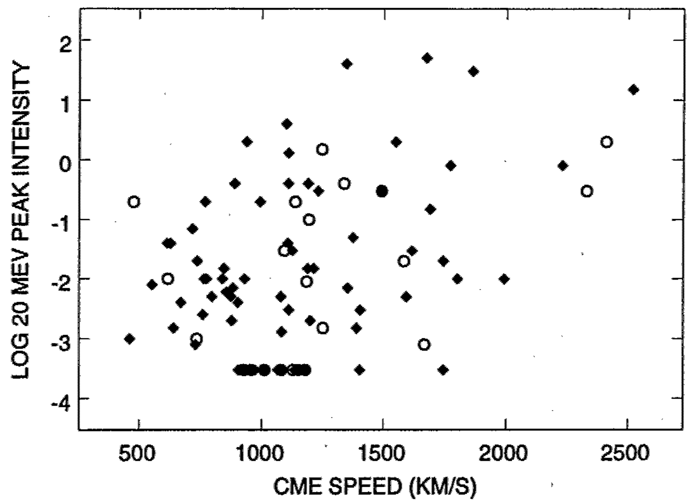

Fig. 2. Logs of 20 MeV peak intensities I_p (p/cm^2 s sr MeV) versus associated CME speeds. Open circles are the 22 CMEs from 1998 to 2002 occurring when $O^7/O^6 <$ 0.15, and diamonds are the 73 CMEs from 1998 to 2000 with $O^7/O^6 \geq 0.15$.

production, which we assume results from CME-driven shocks. In our study we have required the fast CME to occur when $O^7/O^6 < 0.15$ at L1. In several other cases a fast CME occurred just prior to such a period and a peak in the SEP intensity-time profile was clearly seen during the subsequent period.

The surprising result that SEPs occur commonly in fast wind regions suggests that we should examine the basic assumptions of the study: 1) the solar wind flow and Alfven speeds are in fact higher in fast wind regions than in slow wind near the Sun and 2) we understand shock formation and SEP acceleration in those shocks.

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